Relationship between context stability and arousal-driven pupil response in dynamic environments

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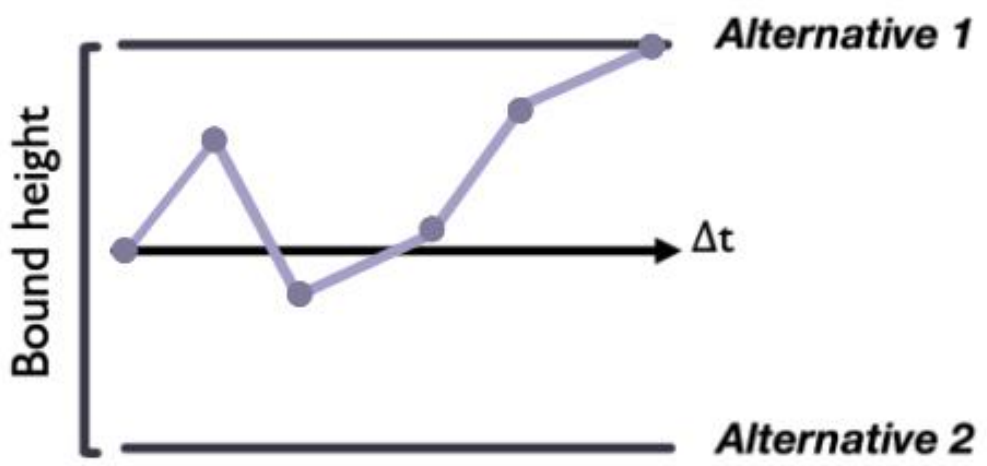
1. INTRODUCTION

- The perceptual decision-making process in noisy environments requires evidence accumulation over time.
- Once the accumulated evidence surpasses the bound height, an alternative is chosen.[1]
- When an environment changes and the current evidence differs from previous accumulated evidence, the arousal system is activated as a result of the surprising event.
- Some environments are more unstable than others.
  - Earlier work has examined the leakiness of evidence, or the weighted priority of recent over old evidence, in more unstable environments.[2]
  - More recently, we have begun to examine the effect of context stability on arousal response.



- The pupil light reflex (PLR) is a response that regulates pupil size in order to control the amount of light that enters the eyes.[3]
  - The PLR can be activated as a result of lighting conditions, where a sudden exposure to bright light can cause a pupil constriction.
  - This reflex can also be activated as a result of non-visual cognitive mechanisms, such as those involved in memory and attention.
  - One cause for non-visual activation of the PLR is surprise.
  - Both the presence of unexpected stimuli and the absence of an expected stimulus can trigger the pupil light response.
- A surprising stimulus can activate the locus coeruleus (LC) brainstem, which relaxes the parasympathetic drive and enhances the sympathetic drive.
  - As a result, surprise-driven LC activation results in a pupil dilation.[3]
- In order to understand arousal response in changing, unpredictable environments of high and low switch frequencies, we examined the pupillometry results during a random-dot motion task.

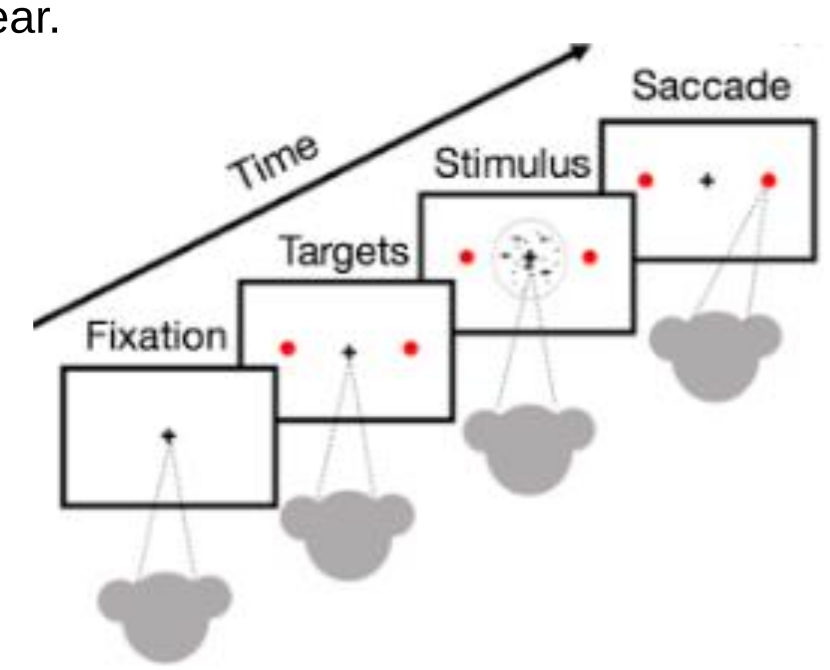
2. HYPOTHESIS

- It is hypothesized that the arousal response to change is dependent on the stability of the environment.
- More specifically, it is hypothesized that the arousal-driven pupil response to a given change event will vary depending on switch frequency conditions in that context.

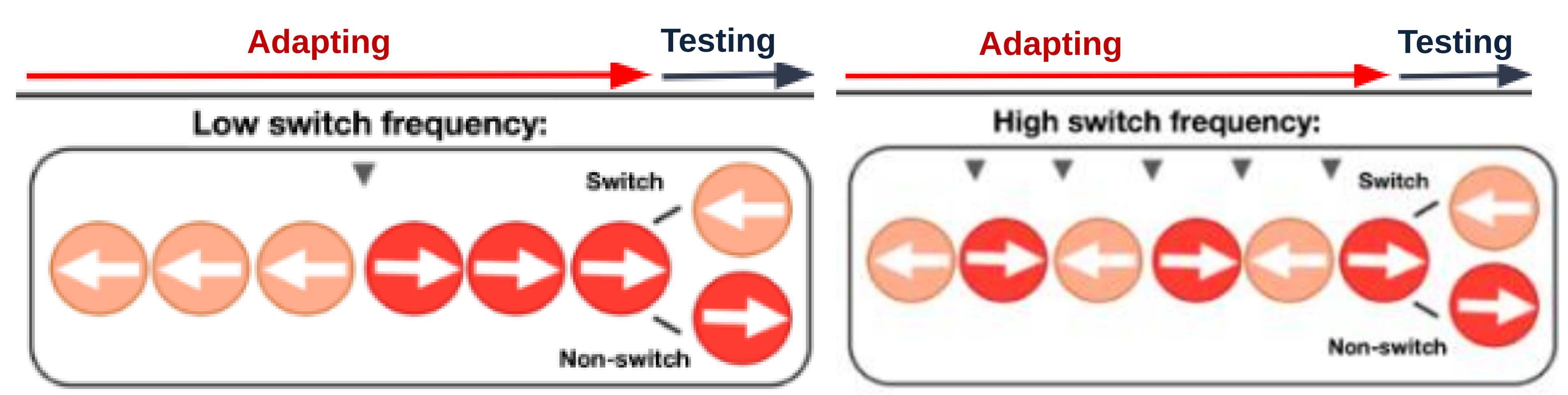
3. METHODS

Dots-Reversal Task

- The LC brainstem activates in response to change points, so we examined the pupil dilation data that occurred as a result of a random-dot motion dots-reversal task.
- During each trial of this discrimination task, a monkey begins by fixating on a dot on the center of a screen, and then a collection of moving dots appear.
- The task consists of two epochs
  - **Adapting epoch**: dots reverse directions according to the switch frequency of that trial (2400 ms)
  - **Testing epoch**: dots reverse directions or maintain the current direction (100-1200 ms)
- Following the testing epoch, the monkey makes a saccade to indicate choice of a final direction of moving dots of either left or right.



- The moving dots appear at two switch frequencies:
- **High switch frequency** trials have 6 change points (dots reverse directions) during the adjusting epoch.
- **Low switch frequency** trials have 2 change points during the adjusting epoch.



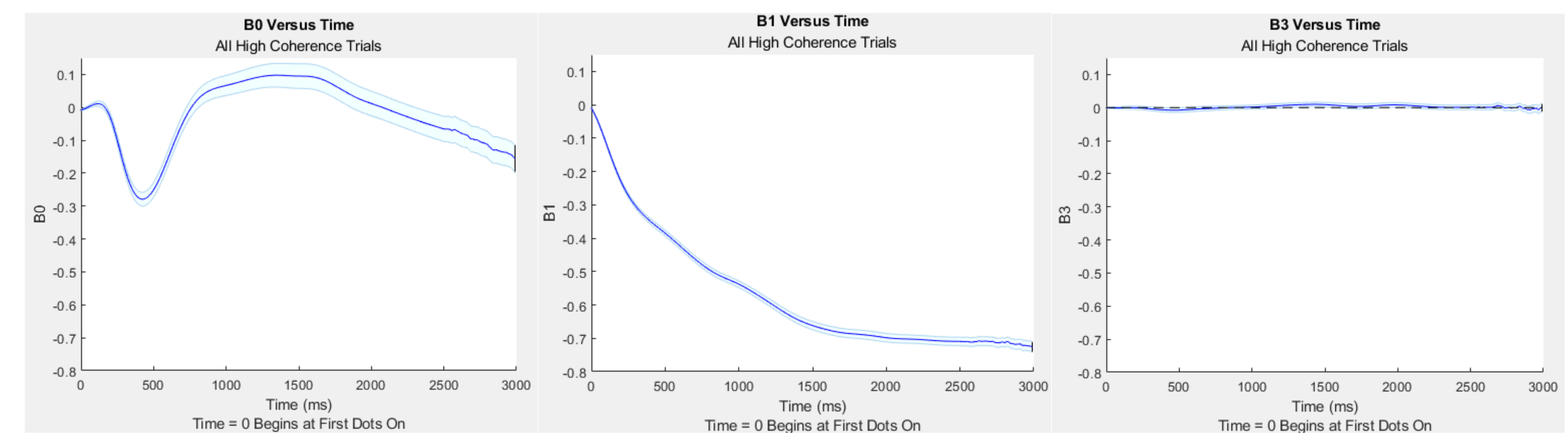
Parameters Influencing Pupil Dilation

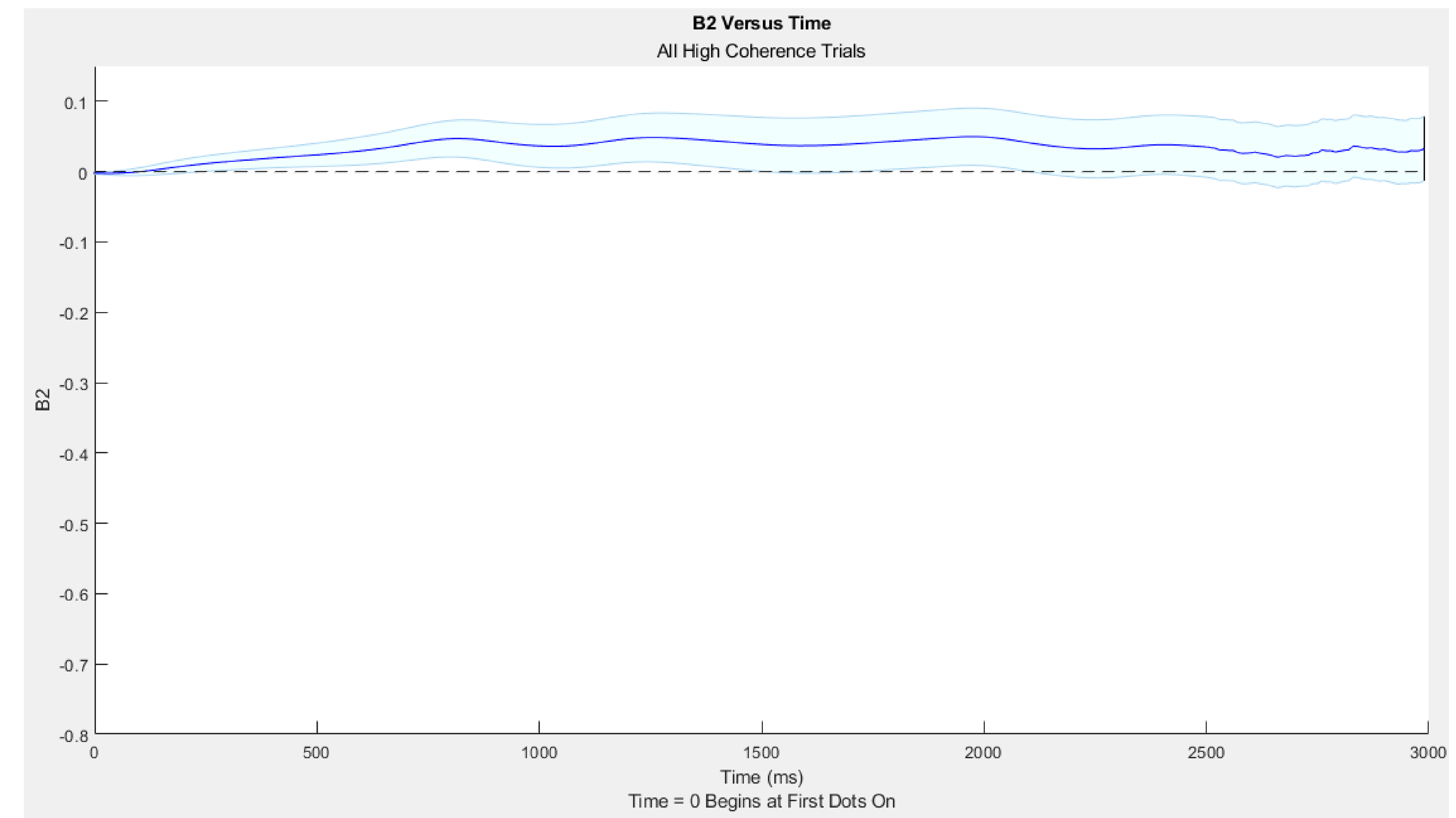
- Baseline pupil diameter affects how much a pupil can dilate. Pupils with a large baseline diameter are less able to further dilate than that of a small baseline.
- Light constricts the pupil. When the screen turns on, the monkey is presented with a bright light. This causes an unwanted decrease in pupil size.
- To determine the influence of the switch frequency parameter on arousal-driven pupil dilation, we ran a rolling window linear regression using parameters to account for:
  - **B0**: Other conditions such as light levels
  - **B1**: Baseline pupil size
  - **B2**: Switch frequency
  - **B3**: Switch/nonswitch for the final change point

Pupil Size Filtering

- Before running the regression model, pupil diameter values were filtered
- Evoked change in pupil diameter was calculated for every diameter value
- The evoked change values were z-scored and passed through a low-pass Butterworth filter
- Trials with low stimuli coherence were eliminated, as well as any incomplete trials

4. RESULTS





- From plots of all parameters accounted for in this model, the influence of each parameter on pupil dilation can be determined by each B value's distance from 0.
- B2, the parameter accounting for switch frequency, is non-zero throughout the trial duration averaged across all sessions.
- These data suggest that context stability may affect arousal-driven pupil dilation response.

5. FUTURE DIRECTIONS

- Collect pupillometric data from a similar but auditory task instead of visual to eliminate noise from screen luminance.
- Record directly from the LC brainstem instead of using pupil size as an indirect measure of LC activity.
- Draw further conclusions about how context has both top-down (pupillometric data) and bottom-up (neural data) cognitive effects.

6. REFERENCES

1. Glaze et al. (2015) Normative Evidence Accumulation in Unpredictable Environments.
2. Gold & Shadlen (2007). The Neural Basis of Decision Making.
3. Joshi & Gold (2020). Pupil Size as a Window on Neural Substrates of Cognition.